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Tunable VHF to SHF Bandpass Filter

The successful amateur construction of equipment requires a certain amount of test gear. A recurring problem is that of the definate identification of high-frequency signals. The driving of mixers and the operation of amplifiers and multipliers in class C all require the positive selection of the wanted signal from the spectrum of frequencies incidently generated by this mode of operation. A tunable bandpass filter is described here which possesses a good Q and can be employed over a wide range of frequencies. The filter is designed around 50 Ω enabling it to be used with standard 50 Ω coaxial interfaces.

1. PRINCIPLE

Fixed tuned filters above one gigahertz are based upon the idea of stub filters comprising a number of intercoupled quarter – or half – wave elements. These filters, according to the number of elements, have either a low insertion loss or excellent selection characteristics. The filter possesses resonant responses at an indefinate number of frequencies above the design frequency. The tuning range is very limited and a continuous tuning with the aid of a calebrated scale is difficult owing to mechanical ganging problems.

In this article a UHF transmitter, using a well known cavity resonator (e. g. that used for the 2 C 39), will be fitted with a tuning drive having a calibrated frequency scale as well as input and output couplings. The tuning range, interestingly, is considerably larger than that using LC or power resonators and is only equalled by magnetically tuned YIG filters. In an actual case there was one filter with a highest tuning limit of 2.9 GHz (plunger fully out) and a lower limit of 280 MHz (plunger fully in). This well nigh fabulous frequency range is, however, also free of overtone and spurious resonances. In addition, the frequency slection was better than 25 dB and the Q was high over the entire tuning range.

On the debit side, an insertion loss of, in general, more than 1 dB has to be taken into consideration. The main strength of this filter lies in measurement analysis possibilities and the cleanliness of the output signal. In conjunction with a suitable wide band detector (thermal or diode) the combination represents a very effective spectrum analyzer.

The resonant circuit consists of a cavity resonator which is excited in the E_{010} mode. By adjustment of the input coupling, it was determined that spurious modes and resonances could not be

provoked . The "hot" point of the resonator was located at the end of the tuning plunger. The deeper the plunger is screwed into the cavity the greater its capacity to the cavity wall as well as an increasing self-inductance along its length. It is because of the combined effects of the LC tuning that enables such an extreme tuning range of over 10 : 1 to be possible.

In the vicinity of the lower frequency limit, the alternating field is concentrated at the end of the plunger. The input coupling probes at the periphery interacts with this field causing a certain amount of mismatch. This causes a deterioration in the return loss together with an increase in the insertion loss of the device. The latter is normally under 1 dB at midrange with resonators that have been silver-plated but at the extreme lower limit the loss could climb to 10 dB. For this reason, the tuning range should be restricted to a limit ratio of between 2 and 3 in order to preserve the insertion loss specifications.

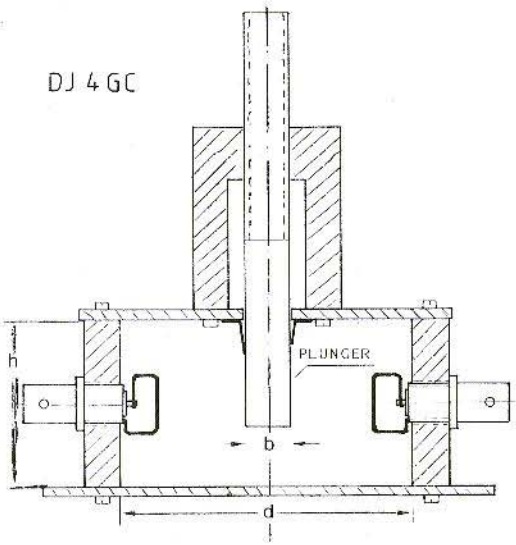

Fig. 1: Construction of a tunable cavity resonator

2. CONSTRUCTION

The mechanical construction in the simplest case can take the form of a length of cylinder complete with top and bottom. Coaxial couplings are let into the sides and the cavity is excited by coupling loops. The depth by which the tuning plunger penetrates the interior of the cavity from one of the lids determines the cavity resonance frequency. The fitting of a mechanical drive and an engraved frequency scale is left to the ingenuity and skill of the constructor. The tuning range, when the tuning plunger is near the cavity floor, becomes very cramped as may be seen in **fig. 3**. The filters discussed in this article have several tuning mechanisms whose merits will be compared. The con-

No	Frequency range (GHz)	Internal height (mm)	Internal diameter (mm)	Plunger dia (mm)	Coupling loop (mm)	Coaxial connectors
1	0.10 – 1.0	85	192	see text	30 x 20	BNC
2	0.28 – 2.9	25	70	19	11 x 6	BNC
3	0.75 – 5.7	15	40	7	7 x 3.5	BNC
4	2.60 – 10.5	9.5	20	4	3 Ø	SMA
5	8.00 – 26.0	4	8	3	1.5 wire	SMA

Table 1

structional representation in **fig. 1** shows the main constructional points of an inductively coupled resonant filter. The figures in **table 1** give dimensions together with the frequency range which may be expected.

Using a diameter to height ratio of 2 : 1, the upper tunable frequency limit may be given by the following approximation: –

$$f_0 \approx 1\ \text{GHz}\ \frac{208\ \text{mm}}{d}$$

where d is given also in millimeters.

The unloaded Q_0 of a cavity with the tuning plunger fully withdrawn is approximated by: –

$$Q_0 \sim \frac{V}{A}$$

where V ≙ Internal volume of cavity (without tuning plunger)
A ≙ Internal surface area

Using silvered cavities which have been polished, unloaded Qs of more than 50,000 can be achieved.

The working Q, and thereby the bandwidth B, is overwhelmingly determined by the degree of coupling. If the input coupling is weak, however, the loaded Q_0 is quite high despite the poor value of the unloaded Q_0 in this region.

The walls of the cavity are made preferably from brass tubing of 5 mm thickness. As this material cannot be readily obtained, and in any case a lathe and BNC / SMA thread cutters would be required, a low cost thin-walled version with cleanly soldered lid joints and flange sockets was constructed. Also, cavities of rectangular cross section display similar characteristics and are very frequently employed as cavity filters.

The first filter detailed in table 1 is only an experimental effort which was constructed from a biscuit tin (**fig. 2**). The tuning plunger (6 mm ø) is fitted with a 50 mm ø plate in order to increase the capacity. Using tin, however, results in a drastic increase in the insertion loss of the device.

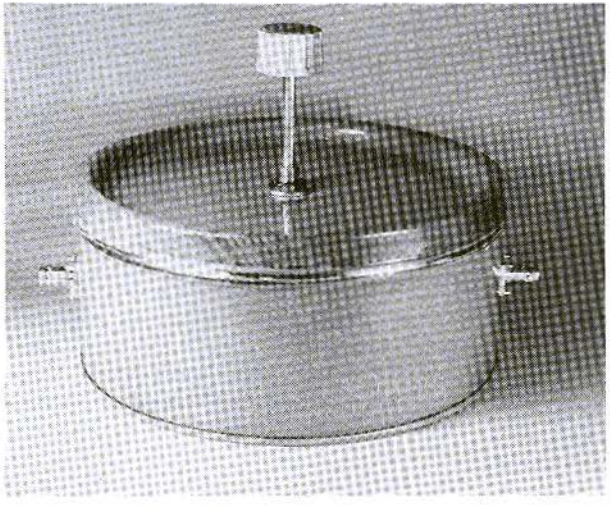

Fig. 2:
VHF cavity (filter No. 1) made from a biscuit tin

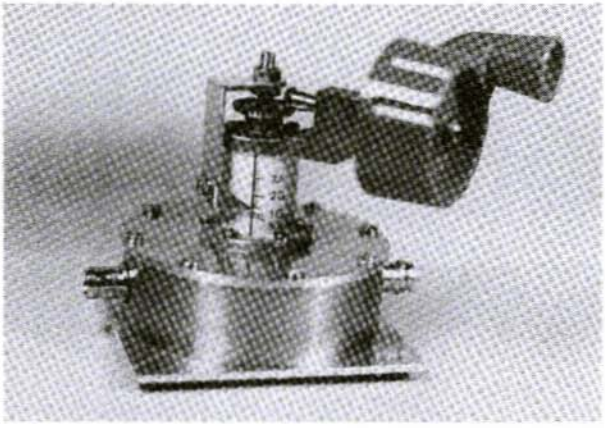

Fig. 3:
UHF cavity resonator (filter No. 2)

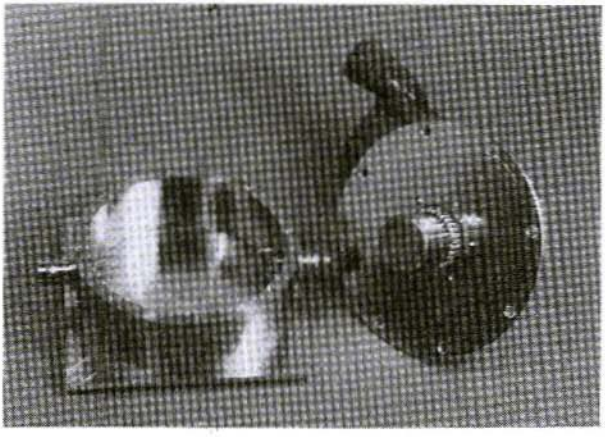

Fig. 4:
Internal construction of the UHF cavity resonator

A tunable UHF resonator is shown in **figs. 3 and 4** and two SHF filters are displayed in **figs. 5 and 6**.

The contacting of the plunger with the lid wall is a key factor in the quality of the cavity's construction. This should preferably be carried out using contact (finger) strip. This may be purchased in metre long strips but material taken from UHF / SHF radio junk can be pressed into service. In particular, cathode and grid holders for coaxial tubes such as the 2 C 39 or RH 7 C are of high quality and are very suitable for this purpose. Cavity diode holders must be worked on a little (6.3 mm) but can be used. Push-pull mixers using diodes in a reversible housing (e. g. 1 N 23 WE): the diode plug-in caps represent a high quality 2.3 mm plunger bush. For the plunger a 2.5 mm diameter length of copper wire can be stretched to obtain a diameter of 2.3 mm. Owing to its small relative diameter, such a tuning spindle should only be used in high frequency cavities. For use at UHF the plunger could be fitted with a capacitive plate of 5 to 10 mm diameter.

Should only a preset or fixed tuning range be de-

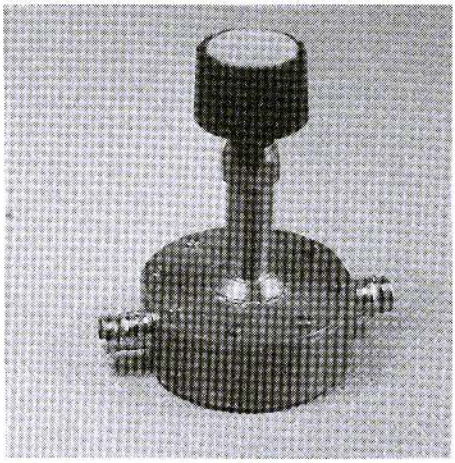

Fig. 5: Filter No. 3, a 750 MHz to 5.8 GHz cavity resonator built by DJ Ø PQ

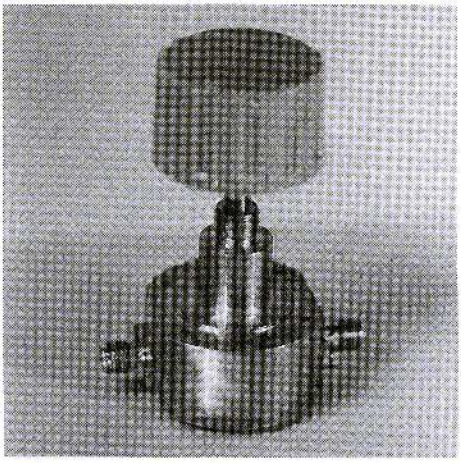

Fig. 6: X - band filter with SMA cennections (No. 4)

sired, the tuning plunger can take the form of a silvered (preferably) brass M 3 to M 8 screw (**fig. 7**) with a suitable locking nut.

In the higher SHF regions a contact-free tuning mechanism is chiefly employed such as that described by DL 3 ER in (1) and (2). This is to be preferred rather than the sliding contacts of the plunger guide. The low pass structure of the plunger guide must, however, be effective at the lowest tunable frequency (**figs. 8, 9 and 10**).

Because of its precision guide system, a plunger fitted with a micrometer is particularly suitable. Such tuning micrometers can often be rescued from S - band or X - band junk.

Instead of the more usual magnetic loop coupling, a capacitive excitation from a short rod or from the inner of a coaxial socket could be used. These coupling elements must, however, be shorter than $\lambda / 4$ at the highest tunable frequency as otherwise, a free-space transmission would

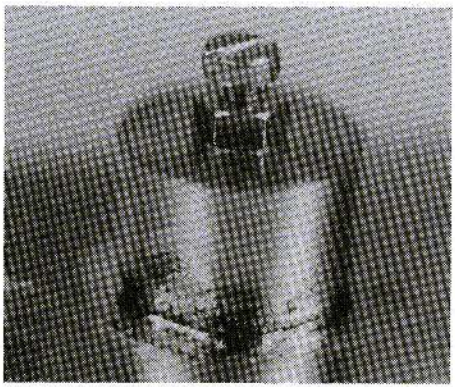

Fig. 7: Printed circuit board X - band resonator with M3 screw tuning plunger

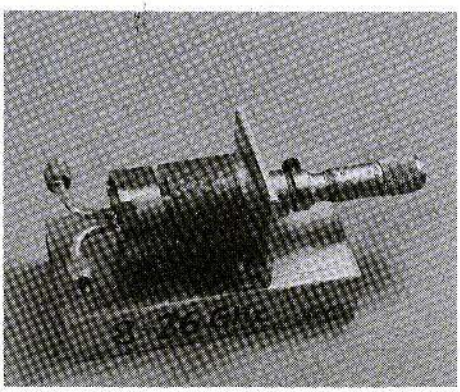

Fig. 8: 8 to 26 GHz through filter (No. 5)

occur. If the coupling is too tight into the resonator, the Q deteriorates and with it the selectivity of the device. A coupling element which is on the short side increases the insertion loss.

In practice, a favourable value is obtained with a radiation length of no more than $\lambda / 8$ (free-space wave length) at the highest tunable frequency. For fixed frequency applications the optimum probe length lies around $\lambda / 10$ which means a length of some 3 mm for X - band work. The distance to the cavity walls would, in this example, be from 1 to 2 mm.

The through filter, shown in **figures 8 to 11**, covers the frequency range from 8 to 26 GHz, i. e. the three millimetric bands X, KU and K. The SMA sockets are not specified for the highest of these frequencies and still higher frequencies require the use of waveguide components.

The cavity resonator has a height of 4 mm and a diameter of only 8 mm. The couplings are formed from the 1.5 mm ends of the coaxial inner conductors (UT 141) shown in **fig. 11**. The free-space distance to the wall is 1 mm. The 3 mm thick tuning plunger is effected by a contact-less low-pass joint in a 3.1 mm drilling. The wall separation is stabilized by a teflon sleeve which has been split along its length. On account of the high resonant frequency the capacitance between plunger and resonator is sufficiently high.

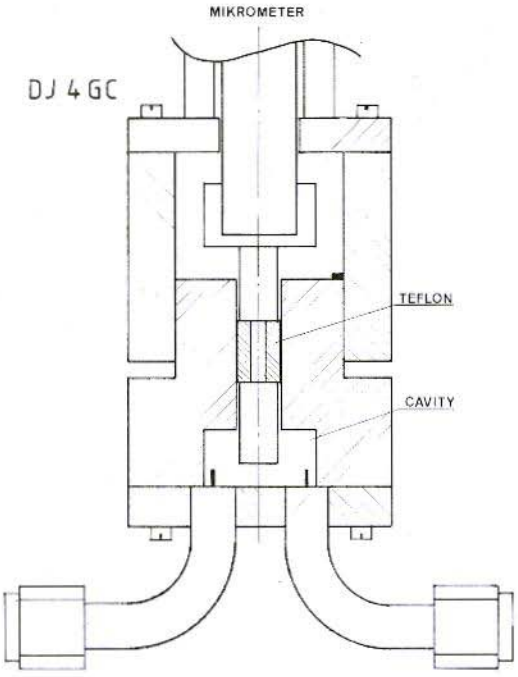

Fig. 9: Constructional details of filter No. 5

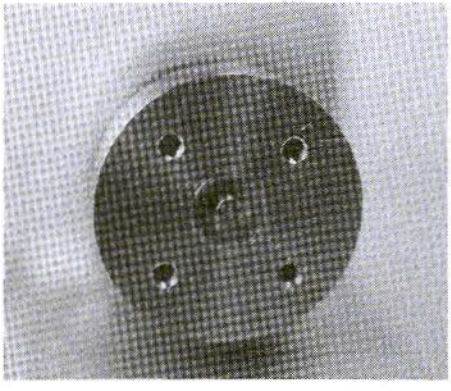

Fig. 10: Resonator cavity with tuning plunger

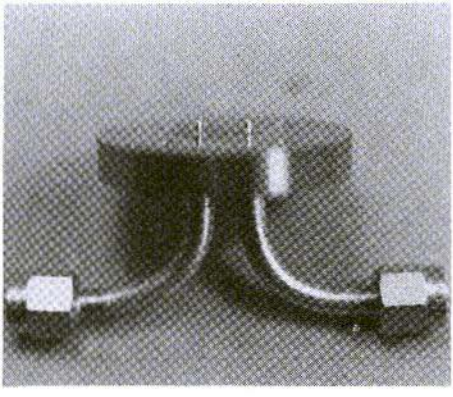

Fig. 11: 1.5 mm ends of the inner conductor of hard coax (UT 141) used as coupling probes

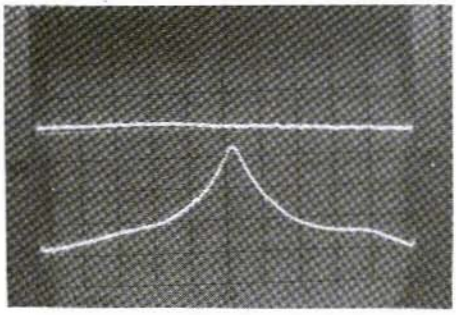

Fig. 12:
Filter No. 2, Centre frequency:
432 MHz, h: 10 MHz / cm, V: 10 dB / cm
3 dB bandwidth: 3.9 MHz, Q = 110,
I_L = 6.5 dB

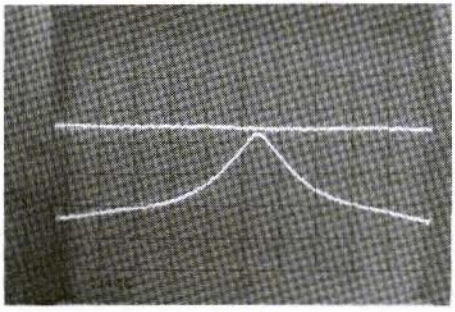

Fig. 13:
Filter No. 2, Centre frequency:
1296 MHz, h: 10 MHz / cm, V: 10 dB / cm
3 dB bandwidth: 5.7 MHz, Q = 227,
I_L = 1.6 dB

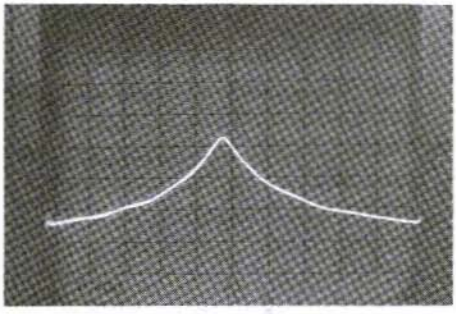

Fig. 14:
Filter No. 2, Centre frequency:
2320 MHz, h: 30 MHz / cm, V: 10 dB / cm
3 dB bandwidth: 15 MHz, Q = 155,
I_L = 1.0 dB

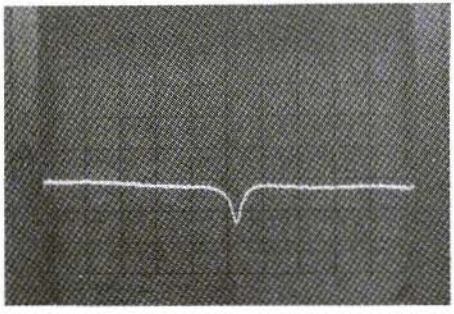

Fig. 15:
Return loss of filter No. 2 in 23 cm band, Centre frequency: 1296 MHz,
h: 10 MHz / cm, V: 10 dB / cm

Using a micrometer plunger drive a backlash free tuning system is assured. The distance of the tuning plunger from the resonator end cap is indicated in one hundredths of a millimeter and may be related to frequency by means of a graph. The selectivity and tuning characteristics in the X - band are quite outstanding but at 24 GHz the stop band attenuation has deteriorated. The display of characteristics in these bands could not be carried out because no sweeper was available.

3. TEST RESULTS

The photographs of **figs. 12, 13 and 14** show the resonance characteristics of filter No. 2 (280 MHz - 2.9 GHz) which covers three amateur bands: 70 cm, 23 cm and 13 cm. On a few measurements, the zero dB reference line can also be seen. The selectivity is always better than 25 dB for all three amateur bands. It is sufficient, for example, to identify a 23 cm band local oscillator frequency at 1152 MHz at a level of 30 dB below the input signal.

The return loss for a high quality termination at 23 cm was measured at 12 dB (**fig. 15**). For specific applications, within an amateur band, the couplings can be optimized to improve the return loss at an acceptable insertion loss (I_L).

The 50 Ω measurement bridge, described by DJ 7 VY, is simple to construct and can be used for measurements of return loss up to 2 GHz with a directivity of about 30 dB. Care must be taken, when using a wide band detector for this purpose, that a signal generator of high spectral purity is used. If necessary, use a filter on the generator output to ensure an accurate measurement which has not been falsified by generator spurious.

The responses of **fig. 16** are from the filter No. 3 (table 1) taken at 5.76 GHz.

The X - band filter No. 4 (**fig. 17**) 2.5 – 10.5 GHz has an insertion loss (I_L) of 1.2 dB at 10.36 GHz. The bandwidth (3 dB) measured by a point-for-point process, was about 40 MHz. The oscillator signal separated by 144 MHz from 10.36 GHz receive frequency, was some 16 dB down on the mid-band attenuation.

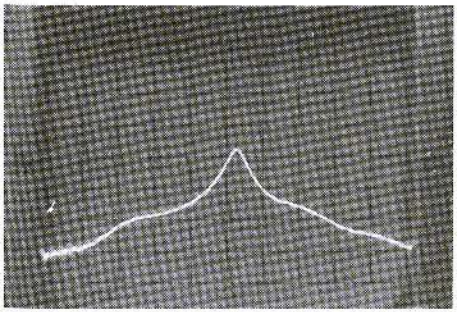

Fig. 16: Filter No. 3, Centre frequency: 5.76 GHz, h: 100 MHz / cm, V: 10 dB / cm 3 dB bandwidth: 35 MHz, I_L = 0.6 dB

Two filters may be cascaded in order to improve the selectivity (**fig. 18**). If the familiar double-hump is apparent, caused by over-critical coupling, an attenuator, of say 6 dB, can be inserted between the two filters. In a specific case, this measure proved unnecessary as filter No. 3 in the 23 cm band already had quite a high insertion loss. The high adjacent selectivity was matched by an adequate stop-band rejection of more than 60 dB.

A suitable indicator on the filter output can be chosen from a spectrum analyser, a logarithmic detector or a thermic power meter. Extremes of

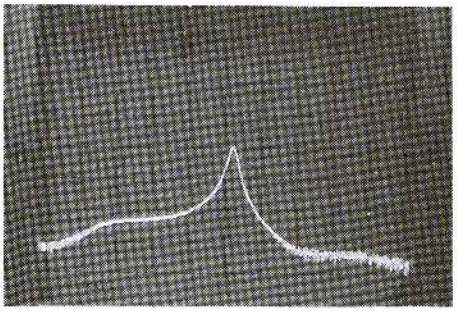

Fig. 17: Filter No. 4, Centre frequency: 5.76 GHz, h: 100 MHz / cm, V: 10 dB / cm 3 dB bandwidth: 22 MHz, I_L = 2.1 dB

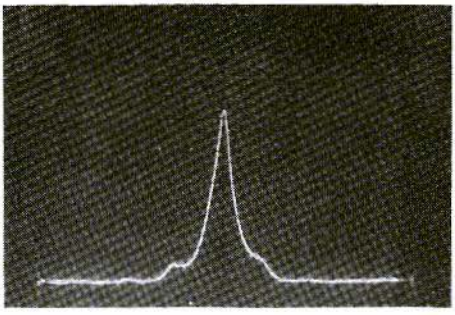

Fig. 18: Filter 2 and Filter 3 in cascade, Centre frequency: 1296 MHz, h: 30 MHz / cm, V: 10 dB / cm l_L (total) = 9.6 dB

power measurements can be aided by the use of a known-gain amplifier to boost weak signals in order that they fall within the dynamic range of the indicator. (Suitable diode detectors will be the subject of a later article).

This measurement system cannot compare with the ease and convenience of a spectrum analyser but it does exhibit similar results at a fraction of the analyser's cost.

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